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RAH-66 Comanche Health Hazard and Performance Issues for the Helmet Integrated Display and Sighting System

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The helmet integrated and display sighting system (HIDSS) is a combination of a protective helmet, helmet mounted display (HMD), and helmet mounted sighting system. It is planned for use in the Army's next generation reconnaissance/attack helicopter, the RAH-66 Comanche. In 1986 and 1988, USAARL developed and published guidelines for addressing potential health hazard issues with the HIDSS. The most recent version of these guidelines was USAARL LR 88-4-21-10, "Revision for the health hazard issues in the HIDSS." This paper is a further revision of these issues. In addition to recommendations provided for performance in the areas of biodynamics, optics/vision, and acoustics, a number of safety and training issues are discussed.

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Background

The U.S. Army is developing the next generation reconnaissance/attack helicopter, the RAH-66 Comanche. Central to pilotage and fire control in this aircraft is the Helmet Integrated Display Sighting System (HIDSS). This system is a sophisticated combination of a protective helmet, a helmet mounted display (HMD), and a helmet mounted sighting system. Since as early as 1986, the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, has been involved in the development of performance requirements for the HIDSS. Under the auspices of the U.S. Army's Light Helicopter Experimental (LHX) program, USAARL developed and published recommended guidelines for addressing health hazard issues for the HIDSS (Biodynamics Research Division, 1986; Barson et al., 1988). The 1988 document, USAARL LR-88-21-4-10, "Revision for the health hazard issues in the Helmet Integrated Display and Sighting System (HIDSS) for the Light Helicopter Experimental (LHX) (Barson et al., 1988)," has been the primary reference for performance requirements for the HIDSS.

Since 1988, evolving medical analyses, improved materials, newer manufacturing processes, and changes in mission requirements and war fighting doctrine have resulted in the need to revisit the health hazard issues related to the HIDSS. This document represents the latest design guidelines for development of the HIDSS. It supersedes those published in USAARL LR-88-4-21-10. Identified performance issues are grouped primarily into three functional areas: biodynamic, acoustical, and optical. Additional issues addressing safety and training are discussed under the auspices of the U.S. Army's Manpower and Personnel Integration and Training (MANPRINT) program. Recommended test and evaluation methodologies for validating the HIDSS design and performance against these guidelines are provided in Rash et al., (1996). However, while based on the latest available data and considered to contain the best recommendations, this document, in part or in total, should not be construed as requirements for the HIDSS unless so directed by the Comanche Program Manager's Office, St. Louis, Missouri. For some parameters, the guidelines presented here are not those of the RAH-66 Comanche HIDSS system specification. In these cases, the HIDSS system specification takes precedence unless otherwise directed.

Biodynamic issues

Biodynamic issues are associated with the total system and/or with the protective helmet itself. These issues impact mission performance and aviator safety during inflight or crash scenarios. In destructive testing, non-functional electro-optical components may be substituted for functional components. However, the mass, center-of-mass (CM), dimensional, and material properties of the non-functional components shall represent fully the operational components. Weight-equivalent dummy cables that are severed within 30 centimeters (cm) from the exit of the helmet shell may be substituted for operational cables, i.e., communications, power supply, fiber optics, etc., for the mass property evaluations.

The reference coordinate system for the mass properties measurements shall be the head anatomical coordinate system in Figure 1.

Mass properties

Mass properties include those of head supported weight and CM of the system as worn. Recommended values for these properties are based on the following minimum configuration: outside shell, energy-absorbing liner, suspension system, retention system (including chin and nape straps), communication system, noise attenuation system (earcups and/or earplugs), visor(s), HMD, circuitry and connection cables for communications and sighting devices [30 cm of cable(s) from the exit point of the helmet shell], and mounting provisions for O_2, nuclear, biological, and chemical (NBC) protection system, and Aviator's Night Vision Imaging System (ANVIS).

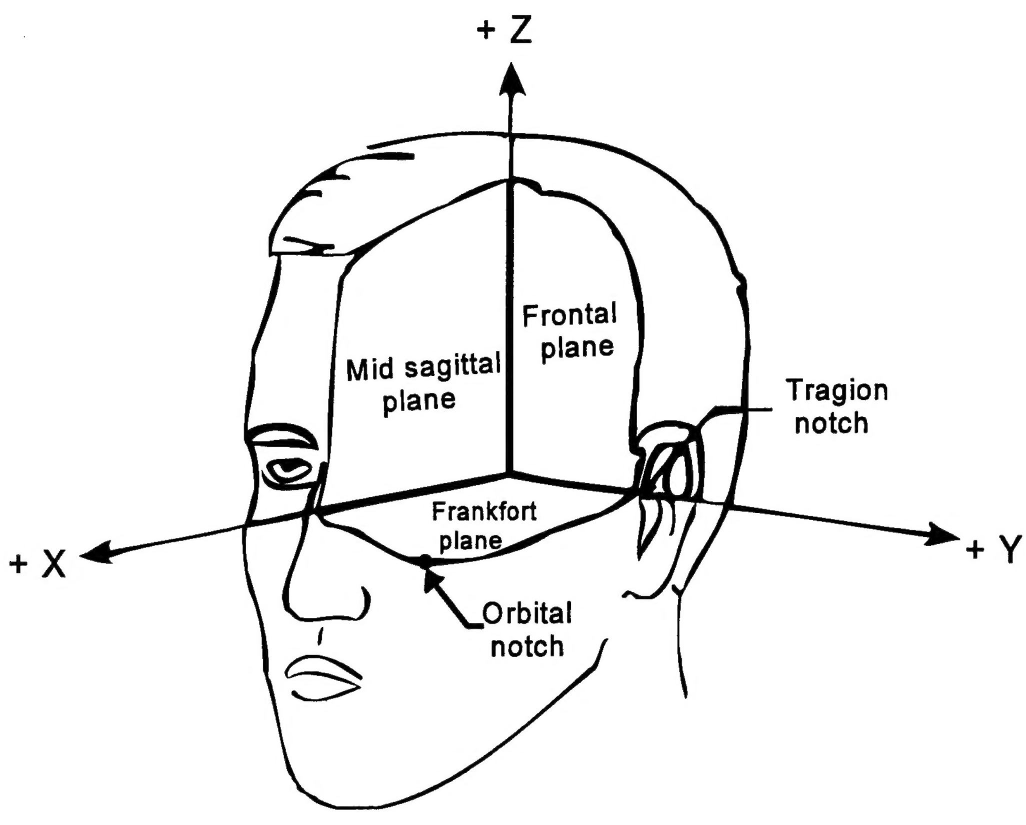

Figure 1. Head anatomical coordinate system.

The allowable HIDSS mass is related to the X- and Z-axis CM locations as shown in Figures 2 and 3. When the X-axis CM value is plotted against the recorded mass on Figure 2, this point shall lie in the acceptable region, below the constant moment curve. When the Z-axis CM value is plotted against the recorded mass on Figure 3, this point shall lie to the left and below the constant moment curve and maximum allowable mass and CM limits. The Y-axis CM location shall lie within 19 mm of the midsagittal (XZ) plane.

The maximum allowable mass, regardless of CM values, is 2.5 kg for helicopter cockpits without airbags and 3.0 kg for helicopter cockpits with airbags.

The maximum Z-axis CM value, regardless of HIDSS mass, is 52 mm. The Z-axis constant moment curve is defined by the equation: vertical CM = [(298/mass) - 119.4]. The X-axis constant moment curve is defined by the equation: longitudinal CM = [(108.05/mass) - 20.0], but shall be no less than -20 mm. The Y-axis CM value shall lie within 19 mm of the midsagittal plane. These requirements address the estimated threshold of survivability, but do not incorporate user acceptability, aircrew performance, fatigue or long term health effects. Mass and CM measurements shall be performed for each identified HIDSS configuration.

Impact attenuation

Deceleration levels of a magnesium headform representing the 50th percentile male fitted with a complete HIDSS shall be measured for impact with a flat anvil at seven helmet locations. The peak acceleration for each impact shall not exceed the maximum G-force thresholds for the impact locations and velocities given in Table 1. Impact locations are defined by Figure 4. Each impact location shall be subjected to a single impact.

Table 1.

Impact attenuation maximum G thresholds.

Impact location	Impact velocity (m/s) Minimum	Maximum	Drop height (meters)	Maximum G*
Crown	4.88	4.95	1.22	150
Left earcup	5.98	6.05	1.83	150
Right earcup	5.98	6.05	1.83	150
Front	5.98	6.05	1.83	175
Rear	5.98	6.05	1.83	175
Left side	5.98	6.05	1.83	175
Right side	5.98	6.05	1.83	175

* Some method, such as high speed photography, shall be used to verify that electro-optical component displacements do not constitute hazards to the face and/or head.

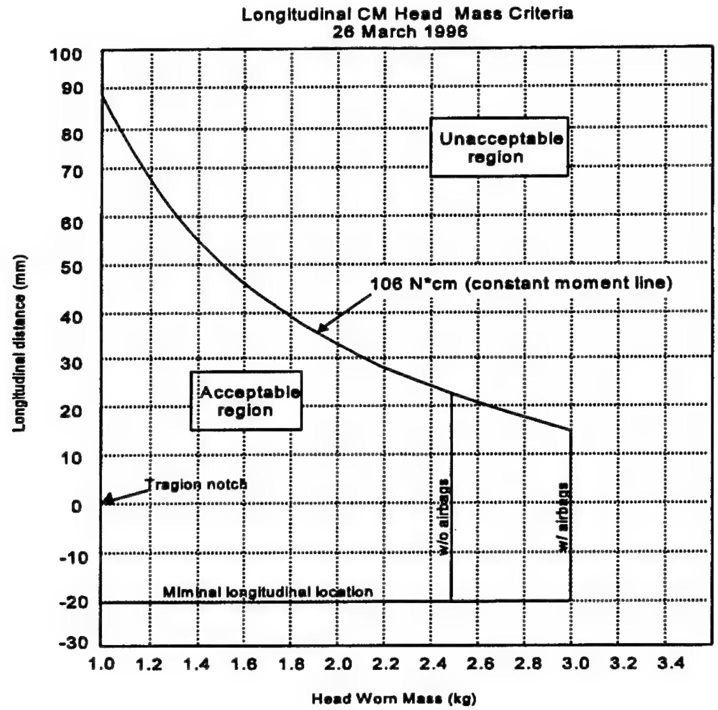

Figure 2. Head worn mass criteria, radial distance, Frankfort plane.

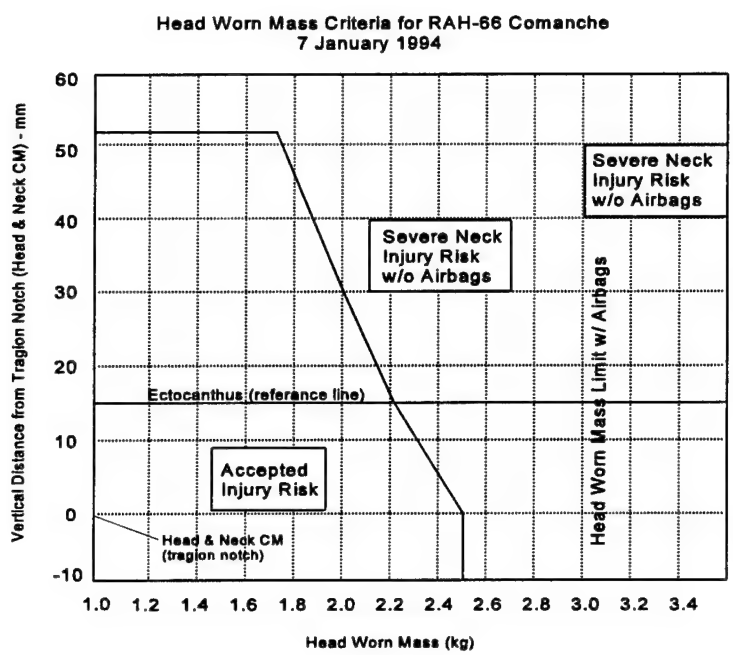

Figure 3. Head worn mass criteria, z-axis, constant moment curve.

The complete HIDSS assembly shall be tested. Non-functional electro-optical components may be substituted for functional components, but must retain the mechanical properties (dimensions, materials, weight, strength, density, yield points, etc.) of the functional system.

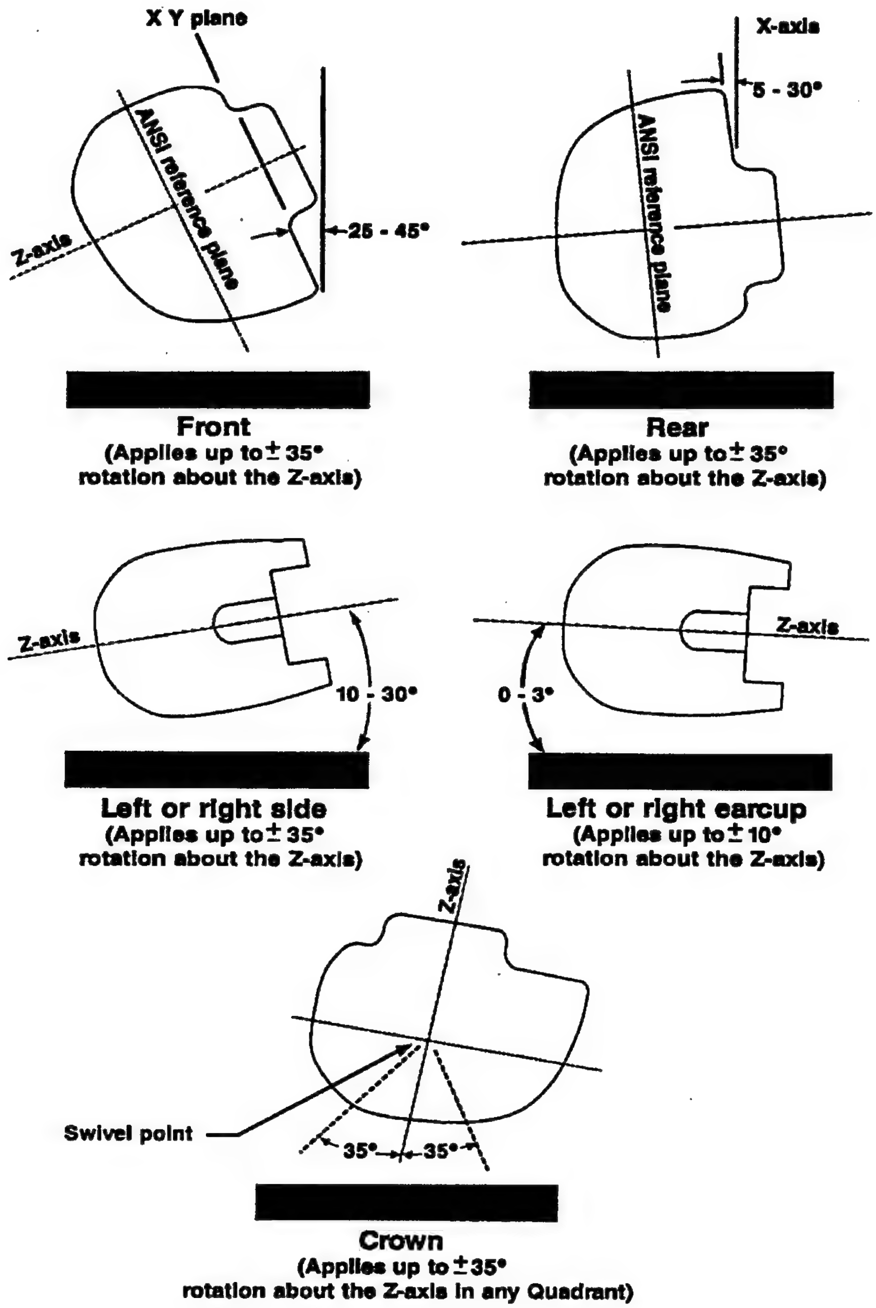

Figure 4. Impact test locations.

Stability

It is important that system stability be maintained when the HIDSS is subjected to various quasi-static torque loadings and vectors associated with flight dynamics. HIDSS stability when subjected to two quasi-static torque loadings and vectors, 6.0 and 60.0 Newton-meters, shall be evaluated. The 6.0- and 60.0-Newton-meter loads reflect low level in-flight and high level crash rotational loadings as applied about the head anatomical origin defined by Figure 1. The angular displacement recorded during a 6.0-Newton-meter torque shall not exceed the amount of HIDSS angular displacement which may result in a 10 percent image loss. The angular displacement recorded during a 60.0-Newton-meter torque shall not exceed the maximum allowable rotation cited by the system specification. The HIDSS shall be evaluated in the configuration assessed as the most potentially hazardous to the user.

The angular displacement resulting from the applied torques shall not result in the optical system or supporting surfaces of the HMD contacting the facial, eye, or forehead regions of a 50th percentile headform, as defined by USAARL Report No. 88-5, Anthropometry and mass distribution for human analogues, Volume I: Military male aviators (1988).

Dynamic retention

Dynamic retention refers to the ability of the retention system to minimize angular displacement of the helmet system during normal flight dynamics. When subjected to a simulated crash pulse, the HIDSS retention characteristics shall be compared against those of the SPH-4B and HGU-56/P helmets. The HIDSS helmet's angular displacement, relative to a test headform, shall be measured by a method similar to the one using a pendulum test device described in USAARL LR 88-5-4-3, Development of a test method for evaluating the effectiveness of helmet retention systems (Gruver and Haley, 1988). The angular displacement resulting from the simulated crash pulse shall not result in the optical system, supporting surfaces, or frames contacting the facial, eye, or forehead regions of the headform.

Anthropometric fit/comfort

The HIDSS shall be capable of accommodating the 1st percentile Natick Army female aviator (Donelson and Gordon, 1991) through the 99th percentile Army male aviator head dimensions with deltas added for use of under the helmet NBC protection. With these deltas, the largest helmet size shall fit a head length dimension of 8.75 inches (22.25 cm), a head breadth dimension of 6.90 inches (17.53 cm), and a head tragion-vertex height dimension of 6.15 inches (15.62 cm). (The cited range does not address non-aviator maintainers.)

The HIDSS shall be capable of being worn by rated aviators during a continuous 3 hour flight simulation period without removal for relief from irritations, headaches, or pressure points

(hot spots). The frequency of in-flight HIDSS adjustments during this simulation period shall not exceed two adjustments per hour.

It is recommended that comfort and fit be evaluated using rated aviator test subjects whose head dimensions correspond with the percentile ranges cited above for selected head parameters. Fit is to be verified by measurement using standard anthropometric measurement instruments and techniques. These data will be recorded for each subject. A flight simulator may be utilized in evaluation of comfort. Environmental conditions of 26 degrees Celsius and 75 percent relative humidity are recommended.

We recommend the following anthropometric parameters be measured prior to fitting. These parameters are identified in NATICK TR-91/040, 1988 Anthropometry survey of U.S. Army personnel: pilot summary statistics, and USAARL Report No. 88-5, Anthropometry and mass distribution for human analogues, Volume I: Military male aviators (USAARL, 1988):

1. ectocanthus - back of head
2. ectocanthus - top of head
3. glabella - back of head
4. head breadth
5. head circumference
6. head length
7. interpupillary breadth
8. tragion - top of head
9. tragion - back of head

The HIDSS configuration used in this evaluation shall be the full display configuration. For each HIDSS size, a minimum of six test subjects, having anthropometric dimensions within the sizing ranges specified by the HIDSS contractor, shall be selected for this evaluation. Each subject shall be fitted with the HIDSS in accordance with the fitting procedures provided by the HIDSS contractor. Any difficulties in obtaining an appropriate helmet fit or acceptable display positioning shall be documented. Once an acceptable fit is obtained, the subject shall be instructed on the proper donning, doffing, and in-flight adjustment procedures of the HIDSS. The subject then shall wear the HIDSS continuously for a minimum of 3 hours in the flight simulator. During the flight simulation, the test subject shall be monitored to record the number of adjustments made by the test subject (i.e., supporting the helmet, loosening or tightening adjustment straps, adjusting earcups, removing or lifting the HIDSS or any component, etc.). After completion of the flight simulation, the test subject shall complete a subjective questionnaire on the HIDSS fitting, comfort, stability, and ease of use.

For anthropometric fit, the recorded anthropometric measurements from both the successful and unsuccessful subject fittings shall be evaluated against the recommended sizing criteria provided by the HIDSS contractor.

For anthropometric comfort, the data recorded by the flight simulator monitor and the subjective questionnaires shall be reviewed for occurrences of HIDSS removal during the flight simulation, severe irritations, headaches or pressure points (hot spots). The frequency of helmet position adjustments shall also be reviewed.

Ballistic protection

The HIDSS system shall provide a minimum V_0 BL(P) ballistic protection of 170 meters per second (558 feet per second) when tested with a caliber .22 (type 2) fragment simulating projectile. There shall be no complete penetration, spalling, petaling, or cracking of the HIDSS shell or protective visor when impacted with a caliber .22 (type 2) fragment simulating projectile at velocities up to 170 meters per second. At least three successful impacts shall be made at velocities between 167 and 170 meters per second. At least two additional impacts shall be made at a projectile velocity between 170 and 172 meters per second. Any projectile impact at a velocity below 170 meters per second which either completely penetrates or causes spalling, petaling, or cracking of the HIDSS system or visor shall result in failure of this requirement.

The projectile impact test for the HIDSS helmet shall be conducted in accordance with MIL-STD-662E, V50 ballistic test for armor, using a caliber .22 type 2 fragment simulating projectile. The HIDSS or visor shall be mounted with the area to be impacted normal to the line of fire. Subsequent impacts shall be aimed at least 2 times the damage diameter away from a previous impact. Impacts shall be at least 2.5 cm from the edge of the HIDSS shell or visor.

The witness plate shall be examined for penetration. A complete penetration is recorded when a hole is located in the witness plate. If no hole is present, but impact is evident, a partial penetration is recorded. The visor shall be examined visually for spalling, petaling, and cracking by holding it up to light to observe the damage.

HMD breakaway force

This issue shall be addressed only if any HIDSS components are designed to release from the HIDSS when subjected to accelerations. The objective of this test is to evaluate the release characteristics of the breakaway components and to ensure that the components do not contact the headform during breakaway.

When subjected to an acceleration of 9 G or less in any vector within the limits described in Figure 5, the designed breakaway components shall not separate from the HIDSS. When subjected to an acceleration of 15 G or greater, in any vector within the limits described in Figure 5, the breakaway components shall separate from the HIDSS.

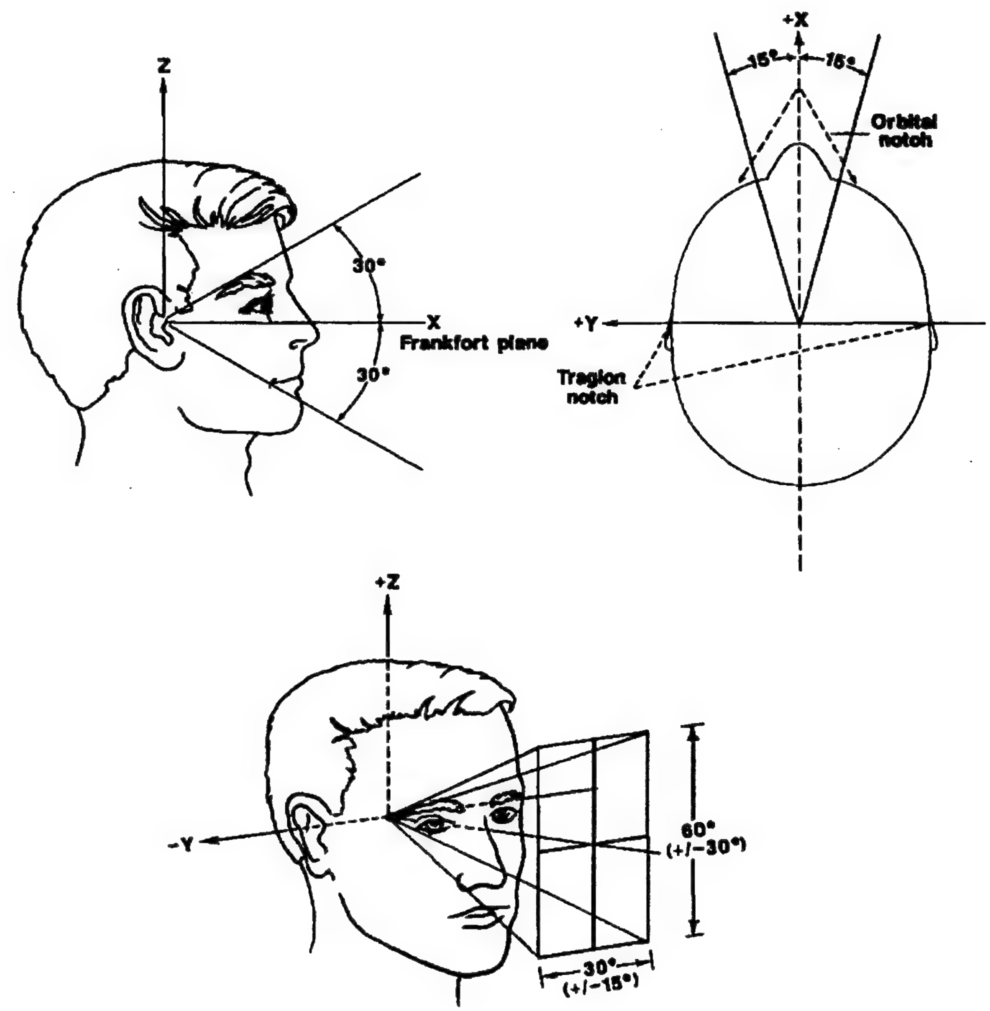

Figure 5. Vector limits for HMD breakaway force.

The breakaway components shall not contact the headform's forehead, eye socket, or facial regions at any acceleration level or vector during these tests.

It is recommended that testing be performed using a standard American National Standards Institute (ANSI) monorail drop tower. The HIDSS system shall be fitted to a test headform in accordance with the fitting procedures provided by the HIDSS contractor. Care shall be taken to ensure that the HMD optics are properly aligned with the headform eye position. The headform and HIDSS system shall be raised to a drop height of 0.5 meter and released in a guided free fall. The acceleration pulse shall be controlled by using various energy attenuating materials to stop the falling headform and HIDSS assembly. The G levels shall be measured with a tri-axial accelerometer and the resultant G level determined. The headform shall be positioned and oriented in accordance with Figure 5. The resultant G levels, headform positions, and breakaway characteristics shall be recorded. Any contact with the headform's facial regions shall be documented, assessed for medical implications, and photographed.

Protective helmet shell tear resistance

The helmet shell shall not allow a tear length greater than 5.0 cm when struck by a 5 kilogram tear penetrator at an impact velocity of 5.4 to 5.6 meters per second.

It is recommended that shell tear resistance be evaluated using a monorail drop tower similar to that shown in Figure 6. The tear penetrator is shown in Figure 7. The helmet shall have the inner components (i.e., earcups, energy absorbing liner, fitting liner, electro-optics, etc.) and any exterior components (i.e., visor, visor housing, etc.) removed to allow testing of the shell. The shell shall be rigidly supported around the penetration area to eliminate shell flexure using a helmet shell support fixture similar to that shown in Figure 8. The helmet shell shall be positioned such that the initial contact point creates a tangent line which is at a 45 degree angle relative to true vertical. The penetrator shall be raised to a height sufficient to create an impact velocity of 5.4 to 5.6 meters per second. The penetrator shall then be released in a guided free fall and allowed to strike the helmet shell. The tear length shall be measured along the outer shell surface and recorded.

Chinstrap assembly integrity

Chinstrap assembly integrity is evaluated by measuring chinstrap system strength and elongation. The helmet integrated chinstrap assembly shall withstand a 1956 Newton (440 pounds) quasi-static tension load for not less than 30 seconds. The total elongation of the helmet chinstrap assembly during this loading shall not exceed 25 millimeters (mm).

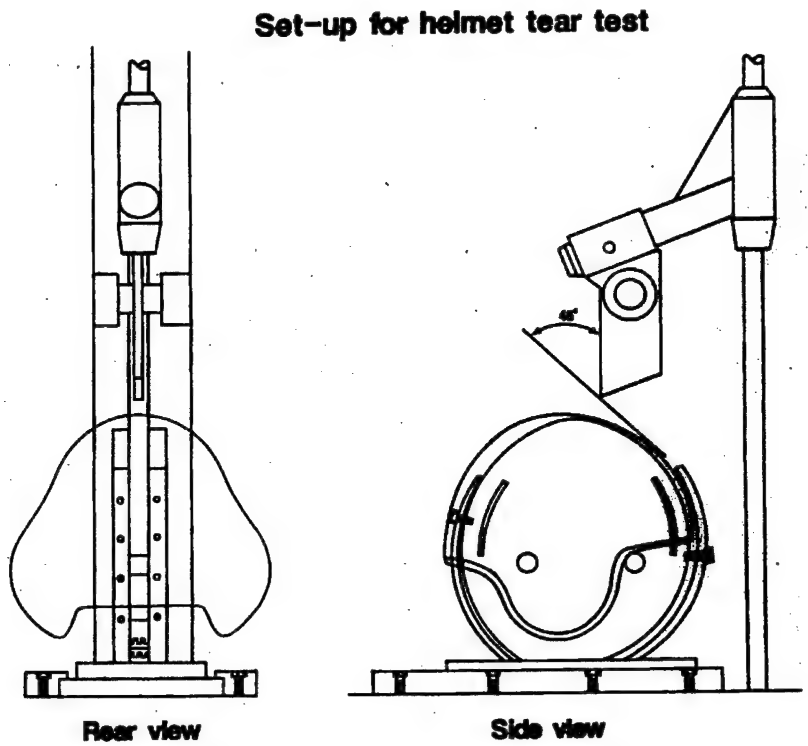

Figure 6. Drop tower setup for helmet tear test.

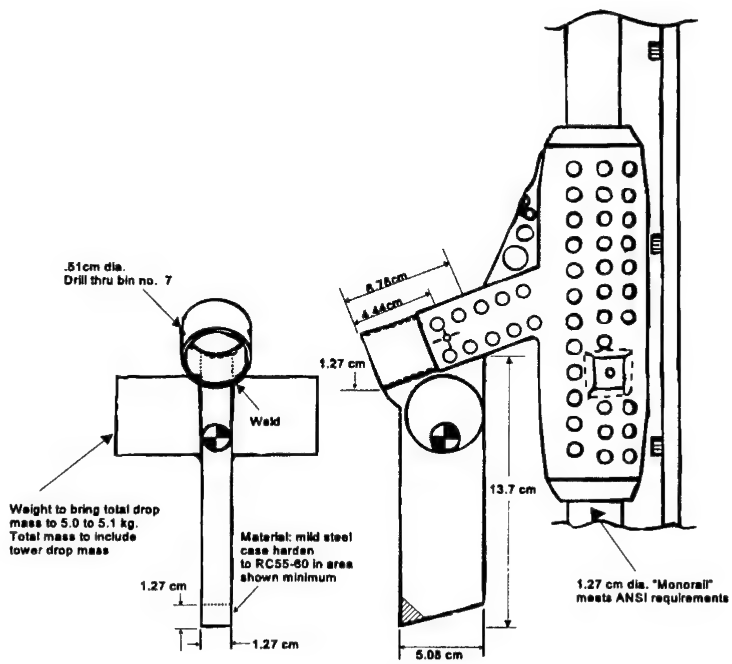

Figure 7. Tear penetrator.

A quasi-static test machine capable of applying and sustaining a load of 1956 Newtons shall be utilized in this evaluation. The HIDSS shall be mounted onto a headform and the chinstrap is routed around a simulated chin. The load is applied through the simulated chin while the headform is held stationary. This test setup is shown in Figure 9.

The HIDSS is fitted to the test headform and the chinstrap is properly routed around the simulated chin. The chinstrap is then pre-loaded to 111 Newtons (25 pounds) and the helmet crown and simulated chin positions are recorded. The load then is increased to 1956 Newtons (440 pounds) and sustained at this level for 30 seconds. Then, the new helmet crown and simulated chin positions are recorded and the load removed.

Total chinstrap elongation is determined by subtracting the helmet displacement from the simulated chin displacement. Total chinstrap elongation (C_T) is calculated by:

$$C_T = (C_f - C_i) - (H_f - H_i)$$

where C_i = chin initial position
C_f = chin final position
H_i = helmet crown initial position
H_f = helmet crown final position

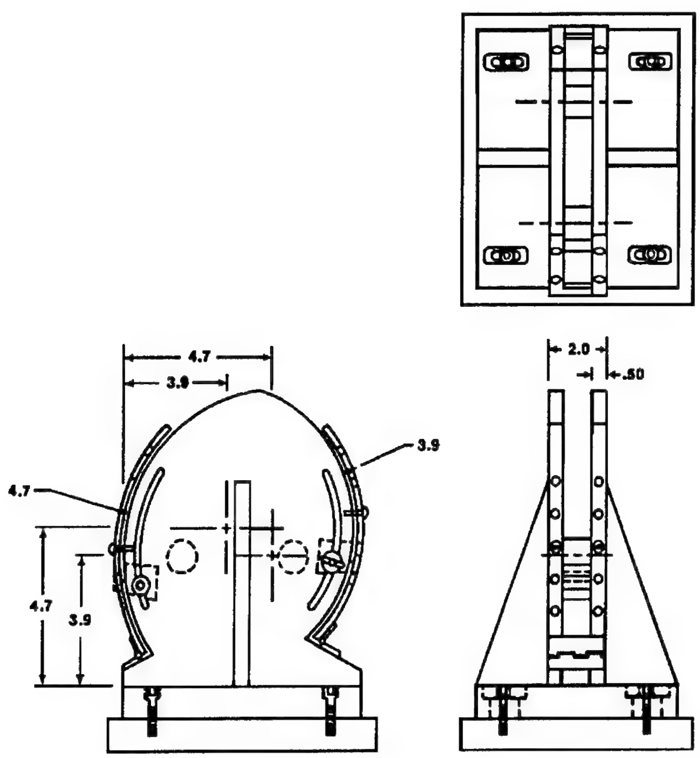

Figure 8. Helmet tear test support fixture.

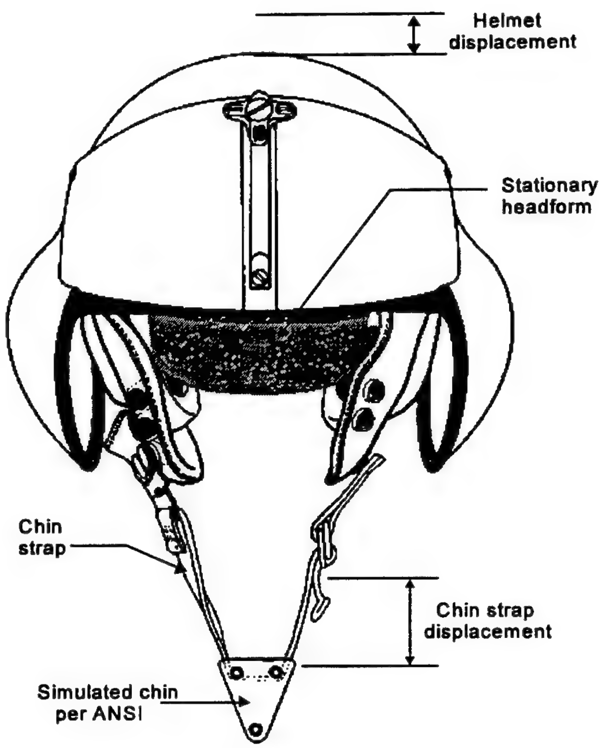

Figure 9. Test setup for chinstrap elongation.

Acoustical issues

Acoustical issues are related to the HIDSS as a total system and to the earphone/earcup subsystem. These issues are: real-ear attenuation, physical-ear attenuation, speech intelligibility, earphone/earcup sensitivity, earphone/earcup distortion, and earphone/earcup frequency response. At present two techniques are being investigated which will improve the sound attenuation and speech intelligibility characteristics of the aviator's helmet. Active noise reduction (ANR) uses electronic circuitry to manipulate and reduce the noise found inside the earcup and is generally effective for frequencies below 1000 Hz. The other technique, Communication Ear Plug (CEP) relies on passive sound attenuation of the earplug in combination with the earcup to achieve the required noise reduction and is effective across the total protection spectrum. Both systems show significant improvements in voice communications over the standard helmet by simple improvements in the speech signal-to-noise ratio. As the selection of the system to be used in the aviator's helmet is made, the design requirements relative to sound attenuation and speech intelligibility will reflect the capability of that system.

Real-ear attenuation

The real-ear attenuation of the standard passive helmet shall be no less than values shown in Table 2 for each of the indicated test frequencies.

Real-ear attenuation testing of the hearing protection characteristics of the helmet shall be performed in a sound room using the ANSI S12.6 (1984) Method for the measurement of the real-ear attenuation of hearing protectors. A standard test consists of approximately 10 normal hearing subjects (verified on a standard clinical audiometer according to ANSI S3.6 (1969), Specification for audiometers) seated in a sound room with their heads placed at a fixed location. The helmet is fitted optimally for each test subject. The subject is instructed to adjust the stimulus level to his auditory threshold for each test frequency using a key pad to increase or decrease the level. This is performed for the three conditions of wearing (occluded) and not wearing (unoccluded) the helmet. The test frequencies are defined as 1/3 octave bands of noise with center frequencies as given in Table 2.

Table 2.

Required real-ear attenuation in decibels (dB).

Frequency (Hertz)								
125	250	500	1000	2000	3150	4000	6300	8000
17	14	20	21	26	38	37	44	42

The mean of the four threshold measurements for each of the test frequencies shall be used as the threshold for the test conditions. The difference in threshold for the occluded and unoccluded trials for each frequency defines the attenuation of the HIDSS for that frequency. These mean values of measured real-ear attenuation shall be compared to minimum required values given in Table 2. Measured values shall be subjected to a student's t-test and shall not be less than values in the table using an alpha of 0.05.

Physical-ear attenuation

Physical-ear attenuation of the hearing protective characteristics of the helmet is determined using the procedure in ANSI S12.42(1995) Microphone in real ear and acoustic test fixture methods for the measurement of insertion loss of circumaural hearing protection devices. A standard test uses approximately 10 subjects with normal hearing. The subjects are required to sit in a hard walled sound room with a semi-diffuse sound field no greater than 105 adjusted decibels (dBA). Attenuation is defined as the difference in noise measured by the microphones located at the ear canal openings while wearing and not wearing the helmet.

The physical-ear attenuation of the left and right earcup shall be the difference in level, in decibels (dB), of the one-third octave test bands between the occluded and unoccluded measurements for each earcup. Measured attenuation of the earcups shall be summarized and reported independently. The standard number of observations shall be approximately 30 (10 subjects measured 3 times each). Results of physical-ear attenuation testing shall be compared to the results of the S12.6 real-ear procedure at each frequency given in Table 2.

Speech intelligibility

It is important to determine the speech intelligibility characteristics of the HIDSS in the specified helicopter noise environment. A score of 91 percent correct speech intelligibility using the Modified Rhyme Test (MRT) is required for the HIDSS when evaluated in the target noise environment.

Speech intelligibility shall be determined in an isolated sound room. The instrumentation will control a calibrated sound field, simulating a helicopter noise environment. Speech samples shall be presented to the subject through the HIDSS using playback instrumentation which provides flat frequency responses from 100 to 10,000 hertz (Hz). The instrumentation shall be capable of accurate gain adjustment with a resolution of 1 dB over a range necessary to vary speech signals at the ear from 10 dB below speech reception threshold (SRT) to 30 dB above SRT for any subject used in the evaluation.

Speech intelligibility shall be determined using a combination of the Modified Rhyme Test and the Phonetically Balanced word test. Testing is conducted using human subjects and performed in a sound field which simulates the target helicopter noise environment. The MRT evaluation shall consist of words presented to the subject through the HIDSS and responses will be made as to which of four possible similar sounding words is the presented word. The total list consist of fifty words.

The speech intelligibility characteristics of the HIDSS is determined by the subjects' ability to understand speech samples of the MRT transmitted through the HIDSS. This ability is directly related to the mean score (percent correct) for word samples presented to test subjects. The mean percent correct for 10 subjects will be tested using a student's t-test and shall not be less than 91 percent correct using an alpha of 0.05.

Earphone/earcup sensitivity

The sensitivity of the earphone/earcup is measured to determine compatibility of the HIDSS with standard Army aviation communication equipment. Sound pressure levels which may exist in the earcup as a result of input from the communication systems shall be determined to provide input to the Health Hazard Assessment.

Sound Pressure Levels (SPL) shall be measured using a flat plate coupler. The earcup/earphone system will be driven by standard audio sound generating equipment. The earcup/earphone shall be placed on a calibrated flat plate coupler. The output of sound generating equipment will be used to drive the earphone/earcup at 1000 Hz with a signal level of 500 millivolts root-mean-square (RMS). The resulting SPL shall be measured and used to compute the sensitivity, SPL/volt.

The measure of sensitivity shall be completed a minimum of three times for each of the samples submitted for evaluation. Mean sensitivity and standard deviation shall be computed for the total sample.

Earphone/earcup distortion

Distortion is a component of speech communication signals which effects the resultant speech quality. Drive levels producing three percent distortion shall be within the intercommunication systems output characteristics. Distortion levels exceeding three percent are considered detrimental to speech intelligibility.

SPLs shall be measured using a flat plate coupler. The earcup/earphone system will be driven by standard audio sound generating equipment. The earcup/earphone shall be placed on a calibrated flat plate coupler. The output of sound generating equipment will be used to drive the earphone/earcup at 250, 500, 1000, 2000, and 4000 Hz. The driving level which produces three percent distortion shall be determined for each of the test frequencies. Measurements shall be completed three times for each sample. Mean sensitivity and standard deviation for each frequency shall be computed for the total sample.

Earphone/earcup frequency response

Frequency response of the earcup/earphone shall not introduce unwanted or extreme variations in sensitivity across the speech spectrum. The frequency response measurement shall be used to provide insight into the speech intelligibility characteristics of the HIDSS.

Frequency response shall be measured, using an artificial ear with flat plate coupler. The earcup/earphone system will be driven by standard audio sound generating equipment. The earphone/earcup shall be placed and centered on the calibrated artificial ear. A wide band noise signal will be input into the earphone/earcup at a level of 85 dBA. The output shall be analyzed to determine the frequency response of the total earphone/earcup system.

The earphone/earcup frequency response shall be evaluated for difference in level relative to 1 kHz for one third octave center frequencies from 250 Hz to 4 kHz. Levels differences shall not exceed 10 dB.

Optical issues

The following optical issues are associated with the HIDSS as a complete system or with the protective visor and nuclear flashblindness subsystems.

Optical configuration

The HIDSS shall be either a binocular or biocular design. However, the HIDSS shall be capable of being operated in a monocular mode with HMD optics obstructing only a single eye.

Visual field

Effective and safe operation in the cockpit is in most cases dependent on the extent of the physical space visible to the aviator's unaided eyes while wearing the HIDSS. This metric is called the visual field. In addition to defining the look-under, look-around capability of the user, it also identifies the presence of system visual obstructions.

From the forward facing design eye position, the available unaided visual field shall encompass all cockpit warning indicator lights. The unaided visual field shall permit viewing of all head down displays and flight instruments without the need for excessive head movement. Reduction in visual field due to system obstructions shall be minimized. Measured visual field data shall be presented graphically. Monocular and biocular fields shall be provided.

Spectral transmittance, chromaticity, neutrality, and ultraviolet transmittance

It is important to determine the amount and frequency (wavelength) distribution of radiant energy which can be transmitted from the outside scene through the HIDSS. The spectral transmittance of a look-through HMD design is allowed to vary with wavelength. However, the measured spectral transmittance shall meet the requirements for chromaticity, neutrality, and ultraviolet transmittance. Spectral data are presented as transmittance curves as a function of wavelength. The spectral transmittance data are used for calculation of chromaticity, neutrality, and ultraviolet transmittance parameters.

Chromaticity refers to a set of color space coordinates. Based on the 1931 Commission Internationale de l'Eclairage (CIE) color space, the HIDSS chromaticity coordinates x and y (Wyszecki and Stiles, 1967) shall be within the limits indicated in Figure 10.

Neutrality is a measure of any altering of the aviator's color discrimination capability when using a look-through system. Neutrality is calculated using the Judd daylight duplication method

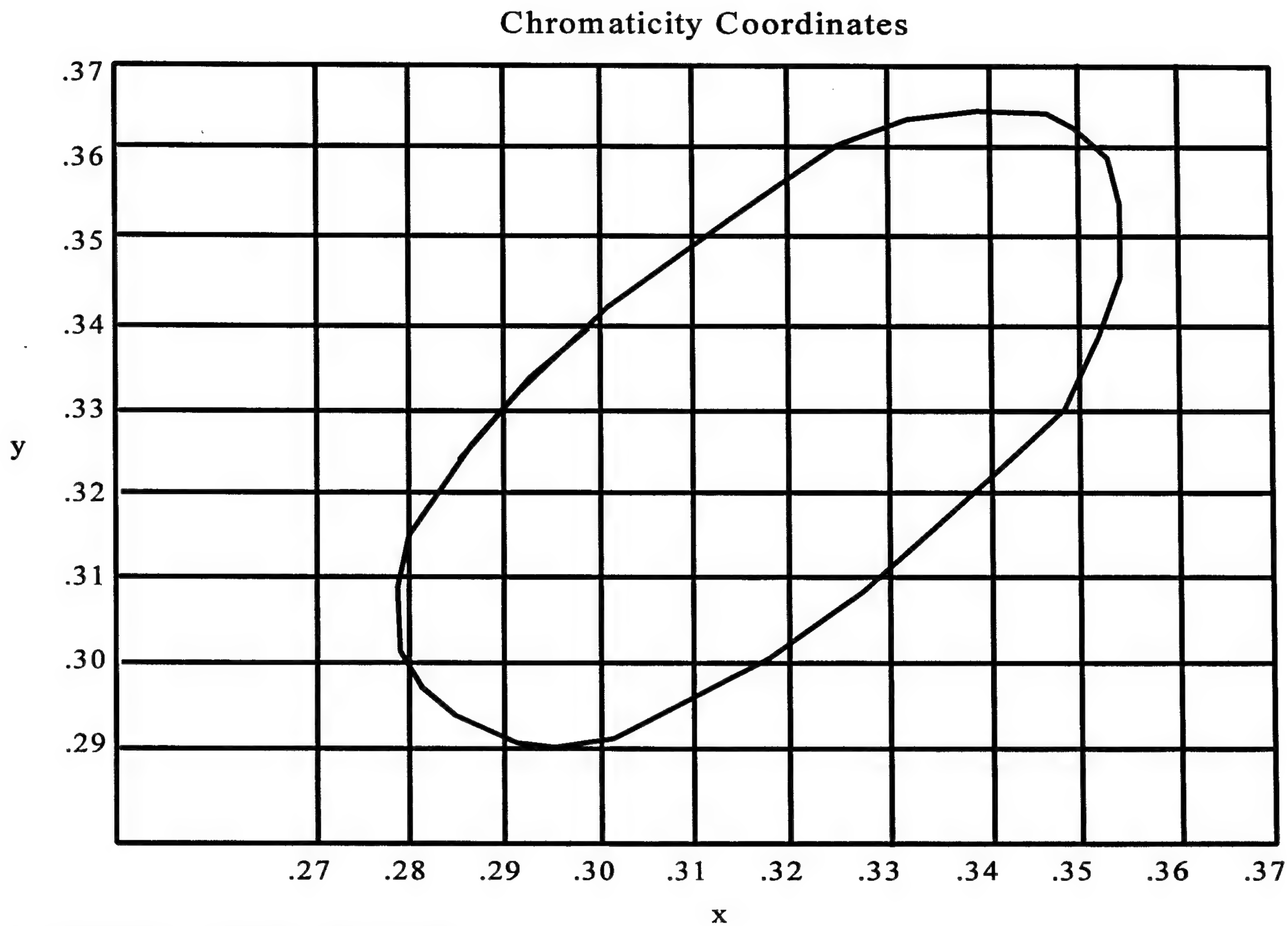

Figure 10. Chromaticity coordinates requirement.

(see paragraph 4.5.8. of MIL-V-43511C) and the spectral transmittance data over the range of 430 to 730 nanometers. The calculated neutrality value (spectral transmittance deviations) shall be less than 12 percent. An exception to this recommendation is for the use of certain special directed energy (laser) protective devices.

Ultraviolet transmittance is defined as the average spectral transmittance at wavelengths of 250, 270, 290, 300, 310, and 320 nm and shall not exceed 1 percent.

Physical eye relief

Physical eye relief (also referred to as eye clearance distance) is defined as the distance along (or parallel to) the optical axis from the last physical element of the HIDSS to the exit pupil of the system.

The eye clearance distance shall be sufficient to allow the use of current or planned aviator corrective spectacles, NBC protective mask, and oxygen mask without reduction in nonvignetted field-of-view (FOV). A value of 30 mm is recommended.

Interpupillary distance (IPD) range

An IPD, or X-axis, optical adjustment is required for biocular/binocular systems so that the optical paths of the display can be adjusted to accommodate the user's dual visual axes. Previously accepted values for IPD range are 58 to 72 mm. The full required field-of-view shall be achievable over the full IPD range. A desired design goal is 55 to 75 mm. Independent adjustment for each eye is preferred.

Luminous transmittance

The measurement of system luminous transmittance determines the amount of visible light transmitted from the external scene through the system to the eye under photopic and scotopic conditions, i.e., see-through transmittance. This measurement shall be performed for all possible system optical media combinations.

Specific criteria for see-through transmittance should be specified in specification documents. If these criteria are not provided, see-through luminous transmittance shall be specified after a careful trade off analysis between display brightness, aircraft transparency transmittance, and range of background luminances for the intended use of the HIDSS. The purpose of see-through vision and display imagery/symbology, e.g., when pilotage is primarily a function of unaided vision and when pilotage is performed primarily with an electro-optical image, should be included in this analysis.

If there are noticeable differences in transmission with different viewing angles from the line-of-sight (e.g., greater than 50 percent difference between the center and a given angle), then the difference in transmittance between the eyes for a given angle of view shall not exceed 30 percent (0.15 log attenuation) of each other.

Prismatic deviation

To determine the total prismatic deviation (vertical and horizontal) between pairs of conjugate points of vision through all combinations of visors, combiners, and/or other optical media of the HIDSS. On-axis and 20 degrees off-axis measurements shall be made.

For vertical prismatic deviation, base up prism shall be designated positive (+) and base down prism shall be designated negative (-). For horizontal prismatic deviation, base out shall be designated positive (+) and base in shall be designated negative (-). Base out prism simulates eye convergence; base in prism simulates eye divergence.

Vertical -- the algebraic difference between the vertical prismatic deviation of the conjugate pairs for the right and left eyes shall be no more than 0.18 diopter nor shall the vertical prism exceed 0.18 diopter at these points.

Horizontal -- the algebraic sum of the horizontal prismatic deviation of the conjugate pairs for the right and left eyes shall not exceed 0.50 diopter nor be less than -0.18 diopter. The absolute algebraic difference between the horizontal deviation at the center points shall not exceed 0.18 diopter.

The vertical prismatic deviation is calculated by determining the algebraic difference between the pairs of conjugate points. The horizontal prismatic deviation is calculated by determining both algebraic sum and difference for the conjugate pairs.

Refractive power

Refractive error refers to the total residual spherical and astigmatic refractive power induced by intervening optical media, e.g., combiners and visors. The total residual refractive power for each optical look-through configuration of the HIDSS using look-through vision shall not exceed +0.12 or -0.25 diopter spherical equivalent or 0.25 diopter of cylindrical power.

Cockpit display emission transmittance

Cockpit display emission transmittance refers to the amount of visible light emitted by cockpit displays which is transmitted through the system to the eye under photopic conditions.

When calculated for the spectral distribution of cockpit display emission sources (e.g., CRT phosphors), the luminous transmittance of all look-through optical configurations shall be equal to or greater than 40 percent or as required by specification documents.

Field-of-view

Display field-of-view refers to the size (horizontal and vertical angular subtense to the eye) of the system's CRT and I^2 displayed imagery at the user-adjusted optimized eye clearance distance and at a 10 mm distance out from the optimized position.

The display field-of-view for the pilotage mode shall meet design specifications and match the field-of-view of the pilotage sensor with unity magnification. An increase in 10 mm of eye relief beyond the optimal user selected position shall not decrease field-of-view by a percentage to be determined (TBD). Display field-of-view shall be presented in a graphical format.

Image overlap

The technique of overlapping two monocular fields in a binocular or biocular HMD design for the purpose of increasing available field-of-view is being used in the HIDSS. It is desirable to measure the size and shape of the right and left monocular fields and the binocular overlapped field of the total display field-of-view. If user adjustable overlap is provided, the range of adjustment shall be measured. Plots of the overlapped region of the total field-of-view shall be provided and compared with the measured display field-of-view.

Unique perceptual problems related to partially overlapped HMDs have been reported (Landau, 1990; Edgar et al., 1991; Klymenko and Rash, 1995). This technique produces a FOV which has a central binocular region and two flanking monocular regions (Figure 11). An unusual characteristic of this design is that the monocular regions are viewed in what is normally a binocular area of human vision. The visual system is primed to receive and interpret binocular information, where the disparity between the images to the two eyes is expected to be small corresponding to the small angular difference between the two eyes. Instead, in the HMD monocular regions, one eye sees a portion of the visual scene and the other eye sees the dark background in the corresponding location. The lack of binocular correspondence in the two images presented to the two eyes results in a visual process known as dichopic competition,

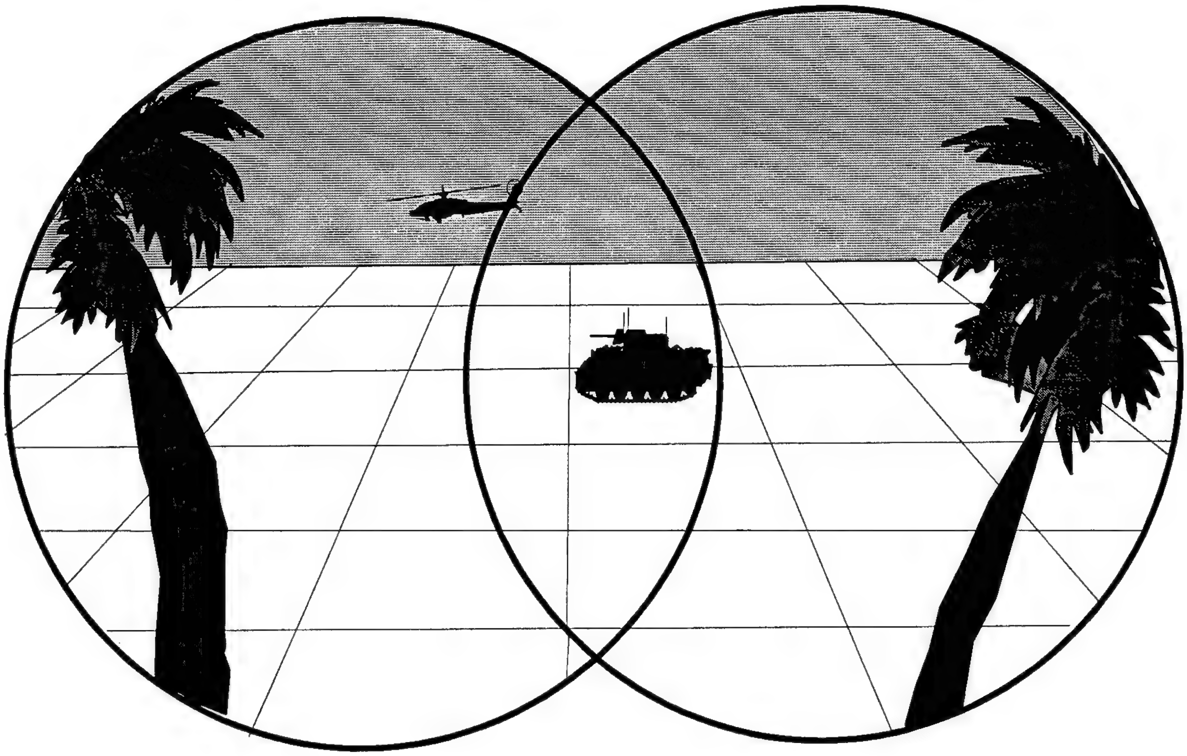

Figure 11. Partial overlapped field-of-view.

which potentially manifests itself as a number of undesirable visual effects. These include binocular rivalry, where visual awareness alternates totally or partially between the images presented to the two eyes, and monocular suppression, where one eye's input dominates awareness at the expense of the other eye.

A perceptual effect which occurs when the wrong eye's image tends to dominate the binocular percept is known as "luning," a subjective darkening in the flanking monocular regions near the boundaries of the overlapped region (Figure 12). Luning is so named because of the moon-like crescent shape of the darkened regions. Luning can cause the FOV, as a whole, to lose its visual continuity, resulting in fragmentation - the appearance of the FOV as three distinct regions. A reduction in target detection capability also has been noted in the darkened luning regions.

Resolution

Resolution addresses a number of issues. These include:

(a) Determining the minimum display luminance required to obtain the criteria resolution for a high contrast target.

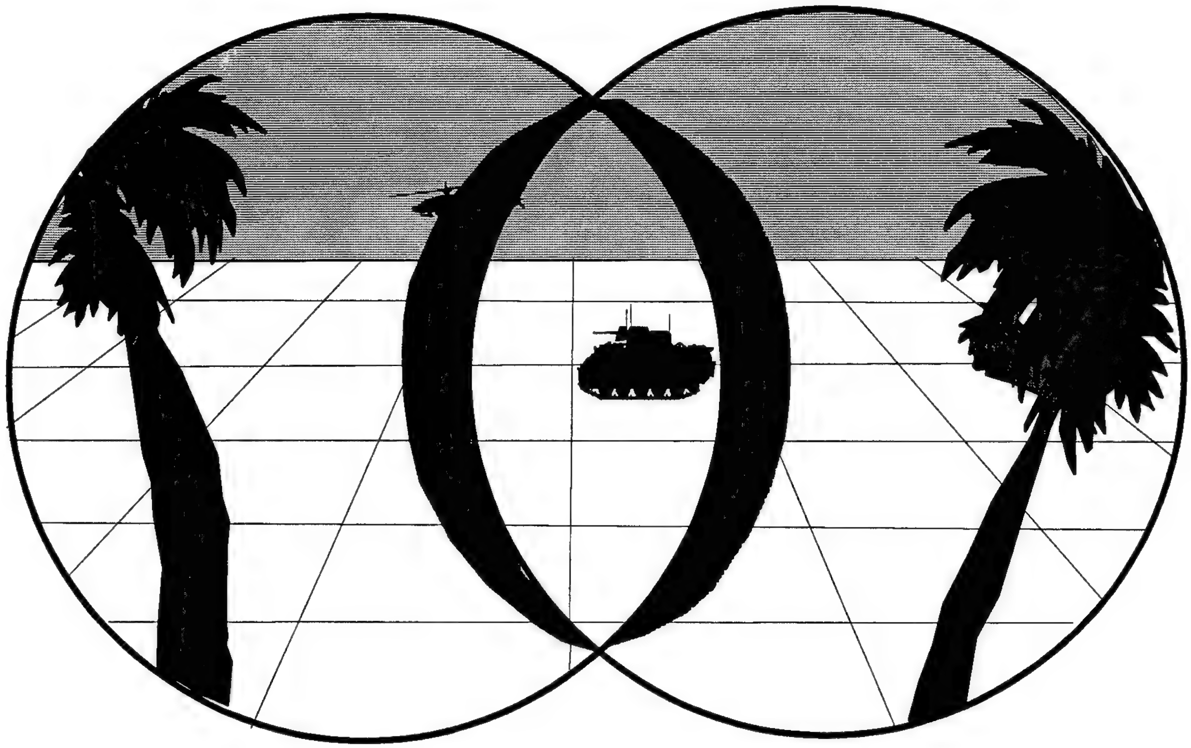

Figure 12. Luning in partial overlap.

(b) Determining the maximum HIDSS subjective resolution with the minimum display luminance with no see-through background luminance (1) with the eye positioned on and off the designed line-of-sight, and (2) with central and peripheral target locations.

(c) To determine the minimum separable resolution of a high contrast video target when viewed against uniform backgrounds of 1, 10, and 100 footlamberts (fL).

(d) To determine the stroke written line widths (50 percent measured luminance point) and character dimensions for for day and image overlaid (night operation) symbology.

The following criteria shall be applied:

(a) HIDSS monocular vertical and horizontal resolution with a display background luminance of less than 10 fL shall be equal to or greater than 0.7 cycles/milliradian (mr) (20/50 Snellen equivalent) for high negative contrast targets in the center of the monocular field-of-view and better than 0.57 cycles/milliradian (20/60 Snellen equivalent) at 0.75 distances from the center to the edge of the field-of-view. With 3 mm of perpendicular displacement from the visual axes, the central and peripheral monocular resolutions shall be no worse than 0.57 cycles/milliradian (20/60 Snellen equivalent) and 0.5 cycle/milliradian (20/70 Snellen equivalent) respectively.

(b) A criterion for HIDSS display resolution for a given background luminance has not been established.

(c) For day symbology, the line widths shall be approximately 1.0 ± 0.7 milliradian at luminance settings appropriate for unaided viewing with background luminance range of 1 to 3000 fL. Noncautionary alphanumerics shall be 7.0 ± 2.0 milliradians (24 arcminutes) in height.

For the subjective measurement of the minimum display luminance to obtain the criteria resolution, the means and standard error of the logarithm of the measured right and left channels for all observers shall be calculated and compared to the minimum logarithm of the background luminance criteria (10 fL) for centrally located targets. Only one background luminance condition is required. The mean and standard deviation of the minimum display luminance for the maximum vertical and horizontal resolutions shall be calculated to fully characterize the display, to include whether contrast and brightness controls were needed to optimize resolution.

The means and standard error of the resolutions, expressed in cycles/milliradian, for visual axes displacements and peripheral targets shall be calculated.

The means and standard error of the resolution for central vertical and horizontal targets when viewed against background luminances of 1, 10, and 100 fL shall be calculated.

Extraneous reflections

The testing for extraneous reflections is accomplished by: (1) Determining the generating location and intensity of ghost (reflective) images from external light sources when using the HIDSS, and (2) Determining the presence and relative luminance of multiple images from the internal imaging source.

Criteria for extraneous reflections with a day and night HIDSS have not been well quantified or previously defined. Any visible reflected images from internal or external sources as seen by the observer will degrade HIDSS or see-through image quality, and these ghost images cannot be eliminated totally with any known HIDSS systems that use combiners. These reflections may be only a minor temporary nuisance for a given condition and viewing angle, or render the HIDSS useless and create a grave safety concern.

A thorough review of potential ghost images from external light sources, to include the range of locations and intensities, shall be conducted for the intended use of the HIDSS. Sources to be included in this list would be the sun, aircraft cockpit lighting, and head down displays.

Some previous values suggested for ghost images have been 5 percent or less. Normally this would be an acceptable value if the reflections are internally generated or are from the instrument lights. However, if the sun is the reflected source, with a 5 percent reflectance, the

reflected intensity as seen by the observer would be approximately 250,000 fL (assuming a sun luminance of approximately 5 million fL). The apparent size of the reflected sun image shall depend on the curvatures of the surfaces responsible for the ghost image.

Based on the previous discussion, criteria are stated as follows:

(a) Display extraneous images shall not induce a safety hazard under any circumstance or significantly degrade performance except under infrequent circumstances, conditions, or situations.

(b) Symbology- For evaluating secondary reflections when using symbology: If the minimum visible symbology in the white portion of the see-through background field-of-view shows a secondary image in the darker field-of-view (10 percent of white), then the HIDSS fails the ghost image requirement.

To evaluate the occurrence of extraneous reflections, the locations of both the luminance source and its corresponding reflective image shall be plotted using polar coordinates. If measurable, the percent reflectance will be calculated from measurements of the luminance of the source and the reflected ghost image.

No secondary images or ghosts shall be visible throughout the image brightness range for raster imagery. However, if they are detected, the measured upper luminance value shall be considered the maximum useable luminance range for calculating display contrast ratio for a given background luminance.

Luminance range

The issues of luminous range include determining the user adjustable raster and stroke luminance range for CRT imagery and determining the ratio of output luminance to input luminance (brightness gain) for helmet-mounted image intensification systems. It also is necessary to determine if the adjustable range of the day symbology is adequate for legibility of stroke symbology when viewing against a bright sky horizon (3000 fL).

The luminance range of raster or image intensification imagery shall be sufficient to conduct nap-of-the-earth (NOE) pilotage in all light levels below that required for unaided vision in see-through configurations. A lower adjustable luminance value for a high positive contrast target is 2 fL or less. An adequate maximum adjustable display value depends on the see-through transmission of the HIDSS design. MIL-A-49425 (1989) requires the brightness gain as seen by the observer not to be less than 2000 fL.

Stroke symbology shall be visible and legible against a background luminance of 3000 fL, i.e., ambient illumination of 9300 footcandles (fc), approximately 100,000 lux. A tinted visor is permitted. Recommended minimum contrast ratio defined as [(symbology + background)/background] is 1.5.

For the I^2 measurement, luminance gain is calculated by dividing the output luminance by the input luminance. Gain values shall be presented graphically as a function of input luminance.

Luminance uniformity

Luminance uniformity is evaluated by measuring the luminance profile of the display. The luminance at any 2 points within a flat field presented on the display shall not vary by more than 20 percent. The luminance values for a minimum of nine points symmetrically within the flat field shall be measured, normalized, and presented as percentages of the maximum value.

Contrast ratio and grey levels

Contrast (here referred to as contrast ratio, C_r) and grey levels [also called shades of grey (SOG)] are interrelated parameters. The HIDSS must be capable of providing adequate contrast in symbology and imagery and of presenting an adequate number of grey shades (square-root-of-two intervals) against a scotopic and a low photopic background. (Note: At this time, there has not been a clear decision on the use of sensor imagery during daytime illumination conditions. Such a decision may require as many as 6 square-root-of-two grey levels against ambient luminance values as high as 10,000 fL. USAARL is currently recommending a upper luminance of 3,000 fL.)

For the purpose of this paper, the following definitions are used:

$$C_r = L_t / L_b \qquad \text{for } L_t > L_b \qquad \text{(Contrast ratio)}$$

$$= L_{max} / L_{min}$$

where, L_t is the luminance of an activated (lighted) element within the imagery, and L_b is the luminance of the background (deactivated or unlighted element).

And,

$$\text{Number of SOG} = \log(C_r)/\log(\sqrt{2}) + 1 \qquad \text{(Grey levels)}$$

Contrast ratios can be determined for symbols and video imagery. SOG are determined only for imagery.

The maximum and minimum adjustable contrast ratios for stroke symbology and raster imagery for see-through background luminances of 0, 1, 10, 100, 1000, and 3000 fL shall be determined.

For day symbology, the contrast ratio shall be adjustable and equal to or exceed a value of 1.5:1 for a 3000 fL background and equal to or exceed 7:1 for a background of 100 fL; both values are based on the use of a tinted visor.

For night imagery, the contrast ratio shall be equal to or exceed the value calculated from the required number of square-root-of-two grey shades in system specification for 0, 1, 10, and 100 fL backgrounds.

The HIDSS specification for contrast and shades of grey is that currently provided in Table II of MIL-L-85762A. This table address high ambient daylight contrast requirements. In this requirement a contrast value of >4.66 with a minimum of 6 shades of gray are required. The 4.66 contrast value (C_L) is based on a definition other than that for C_r given previously. Based on the following definition,

$$C_L = (L_T - L_B) / L_B,$$

the C_L value of 4.66 is equivalent to a C_r value of 5.66 which corresponds to 6 SOG.

USAARL recommends this 5.66 contrast ratio value and 6 SOG be the HIDSS contrast requirement for sensor imagery when viewed against ambient background luminances up to and including 3,000 fL through the shaded visor. For nighttime viewing of sensor imagery, a minimum contrast ratio value of 11.2 which corresponds to 8 SOG is required.

Biocular/binocular luminance disparity

Measurement of luminance disparity in a biocular/binocular system determines the difference in luminance between the right and left HIDSS channels (if system is biocular or binocular) at low, medium, and high luminance settings. If the HIDSS is biocular, only one luminance setting is required. This test is not required if the brightness of each channel can be independently adjusted by the user.

Central field luminance values for the left and right channels shall differ by no more than 30 percent (of the greater) at low, medium, and high mean luminance values of presented imagery. Suggested display values for measurements are 0.1, 1.0, and 10 fL. For an integrated helmet-mounted I^2 device, the upper luminance value of the display shall be at the threshold of where the automatic gain control operates.

The luminance differences between the right and left channels are calculated and compared with system specifications for the three luminance conditions using the following equation:

$$\% \text{ disparity} = [1 - (L_l/L_h)] \times 100$$

Where L_l = luminance of the channel with the lowest luminance value

and L_h = luminance of the channel with the highest luminance value.

Image rotation

The difference in rotation between the right and left HIDSS channels of a cross-hair pattern at the edge of the FOV shall not produce more than 3 milliradians (10 arc minutes) of misalignment, measured perpendicular to the meridian. An acceptable absolute value between the real image and the display rotation for either channel has not been fully investigated. A suggested maximum value is 2 degrees of rotation.

If the image from the HIDSS is rotatable by the user, the amount of possible rotation, both clockwise and counterclockwise shall be measured.

Image size disparity

Measurement of image size disparity determines if images from the right and left channels of the HIDSS are of equivalent apparent size.

Deviations of corresponding image points to each eye as seen by the observer shall not exceed 3 milliradians (10 arcminutes) at the edges of the displays, or any differences in horizontal and vertical image dimensions shall not exceed 1.5 percent, whichever is smaller.

Vertical and horizontal image alignment

Vertical and horizontal image alignment addresses differences in vertical and horizontal positioning of imagery and/or symbology produced by the two channels of the HIDSS.

Maximum vertical deviation between the centers of the displays or central corresponding points for imagery shall not exceed 0.18 prism diopter (1.8 mr, 6.12 arcminutes). For day

symbology presented to both eyes, maximum vertical deviation shall not exceed 0.1 prism diopter (1 mr, 3.4 arcminutes) with both clear and tinted visors.

Maximum horizontal deviation between the centers of the displays or central corresponding points for imagery shall not exceed more than the equivalent of 0.50 diopter (5 mr, 17 arcminutes) of base out prism or 0.18 diopter (1.8 mr, 6.2 arcminutes) of base in prism. For day symbology presented to both eyes, maximum horizontal deviation from a real object as seen by an observer shall not exceed 1 milliradian for clear and tinted visors.

Note: The user may have to have a control for vertical and horizontal display movement to obtain this alignment criteria for binocular symbology with 2 image generators and see-through vision. If the user has alignment adjustments, alignment shall be achievable within approximately the middle 3/4 of the total range adjustment for both horizontal and vertical positioning. A user adjustment alignment range of ±5 mr in the vertical and horizontal is suggested. If adjustments are in fixed increments, the increments shall be less than 1 milliradian, and preferably 0.5 milliradians.

Exit pupil

The size (diameter) and shape of the exit pupil of the display's optics shall be measured. Both on-axis and off-axis measurements shall be performed.

The on-axis exit pupil diameter shall be large enough to prevent reduction of FOV or vignetting under operational conditions (e.g., vibration) for the 1st to 99th percentile target population. Recommended value is 15 millimeters.

The off-axis exit pupil diameter shall be such that no vignetting of the FOV shall occur for ±20 degree eye rotation.

Focus range

There is considerable indication that instrument myopia might be present in binocular systems and is certainly present in monocular HMDs such as the Integrated Helmet and Display Sighting System (IHADSS).

A display focus adjustment capability of at least +1 to -2 diopters is recommended for nonsee-through systems. Markings indicating <u>positive</u>, <u>negative</u>, and <u>zero</u> focus settings shall be provided. A tactile zero value setting marking shall be provided for user awareness.

Distortion

Distortion measurements shall quantify the right and left channel mapping of imagery and determine if geometric correction circuits have been incorporated to sufficiently compensate for probable sensor, electronic, and/or optical distortion.

For biocular/binocular optical systems with fully overlapped fields-of-view, an overall 4 percent distortion value usually has been considered acceptable. That is, a deviation in image mapping towards the periphery of the display could be off by 4 percent, providing the deviation is gradual with no noticeable irregular waviness of vertical or horizontal lines. For a projected display of 40 degree circular FOV and 4 percent distortion, this would mean an object at the edge of the visible field-of-view could appear at 40 x 1.04 (41.6 degrees-- pincushion distortion) or 40/1.04 (38.5 degrees -- barrel distortion).

With biocular/binocular HMDs for overlaying symbology, the HMD will have to meet head-up display specifications of 1 milliradian or less difference between the right and left image channels for symbology within the binocular overlapped area if the symbology is seen by both eyes. Otherwise, diplopia and/or eye strain will be induced.

When imagery is used with a minimum see-through requirement, the maximum displacement between the right and left image points within the biocular/binocular region shall not exceed 3 milliradians (0.3 prism diopter) for vertical, 1 milliradian (0.1 prism diopters) for divergence, and 5 milliradians (0.5 prism diopter) for convergence.

A quantified value for acceptable irregular distortion with imaging devices has not been determined. However, if irregular distortion or diplopia is detected by the trained observers within the binocular area of the display and/or within 20 degrees of the designed line-of-sight, the distortion probably would be considered unacceptable.

In addition, systems using I^2 tubes with fiber optic twists may produce shear effects or "S" distortion, which is covered in image intensification tube specifications.

If distortion is detected, distortion maps shall be made for the HIDSS FOV. One distortion map shall show calculated angular displacement of the vertical and horizontal display lines from the true angular projection, and another distortion map shall show the absolute distances of the perceived display vertical lines.

Static modulation transfer function

The modulation transfer function (MTF) of the raster display shall be measured for low, medium, and high luminance settings at the center and a point 75 percent of the distance from the center to the edge of the FOV. Suggested mean values for low, medium, and high luminance are

0.1, 1.0, and 10.0 fL, respectively. Display MTF shall include all display components from the imaging source up to and including the display optics.

For imagery, the display shall not decrease the sensor/electronic overall MTF or the limiting resolution at the 10 percent modulation point by more than 10 percent at the specified luminance levels in the designed line of regard. Off-axis and peripheral field decreases in MTF shall be less than TBD percent.

The MTF shall be presented as a graph depicting the modulation transfer factor for spatial frequencies.

Dynamic modulation transfer function

The dynamic MTF measures any degradation in the static MTF of the display that occurs due to the dynamic (temporal) characteristics of the display, relative motion within the targeting scene, and/or relative motion between target and sensor. For CRT based displays these characteristics include phosphor rise time and persistence, horizontal scan rate, and vertical field rate; characteristics for flat-panel displays include addressing cycle time, temperature dependent crystal mobility, and suspension media viscosity (Rash and Verona, 1987).

There shall be no measurable degradation in the static MTF caused by image smearing, shearing or serrations for relative target/sensor or relative motion within the targeting scene for relative velocities up to 30 degrees/sec. For velocities greater than 30 degrees/second, there shall be no visibly perceptible dynamic image degradation.

Spherical/astigmatic aberrations

The measurement of spherical/astigmatic aberrations determines the residual refractive power of the HIDSS with lateral and vertical displacement of the eye when measured at the designed exit pupil.

Refractive residual spherical and astigmatic power shall be minimized within the designed exit pupil of the HIDSS. Using a 5-mm entrance pupil, suggested values of maximum variability for spherical and astigmatic errors are 0.50 diopter and 0.37 diopter, respectively, within 4 mm of displacement perpendicular to the designed line-of-sight of the HMD, and no more than 0.75 diopters of spherical or astigmatic variation within the nonvignetted exit pupil. Measurements are made at the center of the binocular FOV (aligned with the designed line-of-sight), at the center of each monocular FOV (aligned with the optical axis), and at 3/4 of the distance from the center to the edge of the monocular FOVs positions. Note: For partial overlapping binocular or

biocular displays, the designed right and left channel lines of sight and the optical axes will usually not coincide.

Hypersteréopsis

Stereopsis is the visual perception of depth derived from a special cue set. The basis for stereopsis is the binocular fusion of images from the two eyes, each having a slightly disparate view of the scene content because of the lateral separation of the eyes. Obviously, there is a learned relationship between image disparity caused by the fixed separation of the entrance pupils of the two eyes (i.e., the IPD) of each person and that person's appreciation of three dimensional space. One version of the HIDSS HMD design is to incorporate two image intensification tubes in a binocular setting, but with the separation distance being approximately 4 times that of the typical IPD. Since the input for the user's perception is derived from the separation distance, it is probable that the user will experience hyperstereopsis, an exaggerated depth perception in which there is a greater sensitivity to small differences in distance and/or depth. This phenomenon has been demonstrated using a laboratory simulation. In the simulation, observers reported that the floor appeared to be bowed in the middle and ramped toward the observer. Also, objects approaching the observed at constant velocity appeared to be accelerating. In a field study (Armbrust et al., 1993) conducted at the request of the Comanche Program Manager's Office, subject aviators reported visual distortions when operating in close proximity to the ground. They also reported that when operating at low hover (< 10 feet), terrain in the immediate vicinity of the aircraft appeared to slope down and in toward the aircraft. Aviators reported the perception of "sitting in a hole" when the aircraft was on the ground.

Protective visors

Visors are classified as Class I (clear, luminous transmittance not less than 85 percent), Class II (tinted, sun protective, luminous transmittance between 12 and 18 percent), or special class (laser protective). Unless otherwise specified, the visor(s) shall have 3 areas of vision: (1) the central portion of each optics (right and left) encompassing an area corresponding to 15 degrees about the optical center as subtended at the eye (referred to as critical vision area), (2) the see-through peripheral area beyond the 15 degrees (referred to as noncritical vision area), and (3) outside the area of vision (no optical requirement). The center point of each optic shall be identified as point "C" and defined as the point of intersection of user line-of-sight on the visor. Most visor tests are as described in or adapted from MIL-V-43511C, Visors, flyer's, helmet, polycarbonate.

Visor performance is defined generally in MIL-V-43511C, Visors, flyer's, helmet, polycarbonate. A summary is provided here. However, overall system performance takes precedence over component performance, e.g., visors.

Refractive power - The spherical refractive power of the visor(s) at the center points and other selected points shall not exceed ±0.125 diopter. The cylindrical refractive power shall not exceed ±0.0625 diopter.

Prismatic deviation - The algebraic difference between the vertical prismatic deviation of the center points (and other conjugate pairs) for the right and left eyes shall be no more than 0.18 diopter nor shall the vertical prism exceed 0.18 diopter at these points. The algebraic sum of the horizontal prismatic deviation of the center points (and other conjugate pairs) for the right and left eyes shall not exceed 0.50 diopter. The algebraic difference between the horizontal deviation at the center points shall not exceed 0.18 diopter.

Both vertical and horizontal prismatic power shall be measured at the left and right center points and at all other points of interest. Measurements are obtained with visors aligned (using test fixture) to replicate "as worn" position (Rash and Martin, 1986).

Base up prism shall be designated positive (+) and base down prism shall be designated negative (-). Base out prism (temporally deflected) shall be designated as positive (+) and base in prism (nasally deflected) shall be designated negative (-).

The vertical prismatic deviation values are determined by calculating the algebraic difference between the pairs of conjugate points. The horizontal prismatic deviation values are determined by calculating both algebraic sum and difference for the conjugate pairs.

Haze - Haze, the amount of light scattered by the visor(s) due to optical imperfections such as scratches, thickness variations, etc., shall not exceed 2 percent. The procedure should be in accordance with that of ASTM D1003-61 (1970), "Test for haze and luminous transmittance of transparent plastics." Measurements are taken at the center point of each lens for each sample.

Distortion - Visors, when used to view a zero distortion test line grating, shall not produce objectionable levels of distortion. Testing is typically performed using an Ann Arbor optical tester (with a 50-line grating). The optical distortion is determined by inserting the device with its surface normal to the line-of-sight into the testing apparatus. Both the right and left optics of the visor(s) shall be tested. A scale of 0-5 is applied, where 0 represents no distortion and 5 equates to a totally unacceptable level of distortion. Two optical areas are evaluated: (1) the central portion of the right and left optics encompassing an area corresponding to 20 degrees about the optical center as subtended at the eye, and (2) the peripheral areas beyond the 20 degrees.

Measurements are made by viewing the zero distortion test pattern through each sample visor and subjectively assigning a scale value to the viewed image. Typically, distortion values of 3 or greater within the central optical area shall be reported as unacceptable. Values of 4 or greater in the peripheral area shall be reported as unacceptable.

Color discrimination - Class I (clear) and Class II (neutral tinted) visors shall not degrade color discrimination. Special Class (directed energy protective) visors shall produce minimum loss of color discrimination.

The Farnsworth panel D-15 and Lanthony's desaturated 15-hue tests, or equivalent, are recommended (Rubin and Walls, 1972). Both tests consist of 16 color chips selected from the Munsell Book of Color. The hues (Munsell hue) are the same in the two tests and are selected so that the intervals between the different hues are approximately equal, but the purity (Munsell chroma) and luminosity level (Munsell value) are different. In the Farnsworth panel D-15 test, the mean chroma is approximately 4.2 and the mean value is approximately 5; in the Lanthony desaturated test the chroma is 2 and the value is 8. As a result, the color chips of the desaturated 15-hue test appear paler and lighter than those of the standard D-15 test.

A plot of the scores is made and compared with known examples of results obtained from both normal and color defective subjects. Although not specifically recommended for these tests, a quantitative scoring scheme designed for the Farnsworth FM-100 test is used to compare small differences in performance in normal observers on retesting with visor samples. The resulting error scores reflect the number of color caps misplaced and the distance that they are displaced from the correct positions.

Optical density - Laser protective visors shall provide adequate attenuation (expressed as optical density) at identified wavelengths. Individual requirements for threat wavelengths are classified. The recommended value for common threat wavelengths is a minimum optical density of 4.0 at 532 nm, 694.3 nm, and 1064 nm. Specific specifications for the HIDSS should be consulted. Any decrease in optical density in the visors resulting from the test exposure shall not exceed 0.5 for angles of incidence of 0 to 30 degrees from the normal for any polarization state of the incident laser radiation.

The optical density (OD) of the sample is calculated using the relationship, $OD = \log_{10} (1/T)$, where T is the measured transmission.

Abrasion resistance - Visors shall provide resistance to scratching and abrasion. After being subjected to the abrasion test, the increase in haze shall not exceed 6 percent and the decrease in luminous transmittance shall not exceed 4 percent. A recommended test is that using a spring loaded abrasion test assembly and standardized eraser as described in MIL-V-22272D(AS), "Visors, neodymium, protective for aircrewman's helmet." The eraser plug is defined in MIL-E-12397, "Eraser, rubber-pumice (for testing coated optical elements)." Haze and luminous transmittance measurements are performed prior to and following this test.

Luminance transmittance - The photopic transmittance of Class I (clear) visors to be not less than 85 percent. The photopic transmittance of Class II (tinted, sun protective) visors must be between 12 and 18 percent at the center points and not vary more than 3 percent.

Further guidance from Natick Research, Development, and Engineering Center, Natick, Massachusetts, on laser protective visors for the SPH-4B aviator's helmet states the photopic luminous transmittance shall not be less than 40 percent for the "light" laser protective visor and not less than 10 percent for the "dark" laser protective visor. This same guidance requires the scotopic transmittance to be not less than 40 percent for the "light" visor and not less than 9 percent for the "dark" laser visor. The terms "light" and "dark" are interpreted to mean "2-notch" and "3 (or greater)-notch," respectively.

In addition, recent unpublished work at USAARL has tentatively recommended a minimum transmittance of 30 percent during light levels consistent with dawn, dusk, and full moon.

Ultraviolet transmittance - The ultraviolet transmittance is computed as the average spectral transmittance at wavelengths of 250, 270, 290, 300, 310, and 320 nm. This value shall not be more than 1 percent.

Neutrality - Neutrality is measured only for Class II (tinted, sun protective) visors and insures a uniform distribution of transmitted energy throughout the visible spectrum (430-730 nm) to minimize color distortion. The spectral transmittance may vary with wavelength between 430 and 730 nm. The neutrality is calculated by the Judd Daylight Duplication Method. This method requires calculating the average spectral transmittance deviation for 9 spectral bands between 430 and 730. (See paragraph 4.5.8. of MIL-V-43511C.) The calculated spectral transmittance deviation (neutrality value) shall be less than 12 percent.

Chromaticity - Chromaticity is calculated for Class II (tinted, sun protective) and Special Class visors. The 1931 Commission Internationale de l'Eclairage (CIE) chromaticity coordinates x and y shall be within the limits indicated in Figure 10. (Wyszecki and Stiles, 1967).

Visual defects - Visors shall be examined for the presence and frequency of visual defects, e.g., scratches, blemishes, sharp edges, cracks, etc.

MIL-V-43511C establishes criteria for visor visual defects based on classification of these defects as critical, major, or minor (MIL-V-43511C, Table I, page 7). No critical defects are allowed. The number of major defects shall not exceed 2.5 per hundred visors and the sum of the major and minor defects shall not exceed 4.0 per hundred visors.

Additional criteria have been developed in support of the IHADSS program. IHADSS specification ES33830-01 defines the level of the optical defects to be applied in the inspection of IHADSS visors. These criteria involve a classification of defects as gross flaws or blemishes with further description of spatial frequency as to a single defect or a cluster of defects. Under the IHADSS criteria, no gross flaws (single or cluster) are allowed in the critical viewing area and no more than five blemishes are allowed in the critical viewing area.

A uniform background fluorescent light source and a measuring device with 0.01 inch minimum resolution are used. The alternative procedure requires two 15-watt fluorescent tubes and a black matte background.

Using the naked eye at a viewing distance of 10-14 inches, visors shall be visually inspected for the presences of any pit, dig, scratch, bubble inclusion, blister, crack, hole, chip, break, cloudiness, abrasion, striae, stain, discoloration, burr, or other visible defect. Each defect is recorded with respect to type, size (length and width or diameter), and location (critical, non-critical, or outside area of vision).

In an alternative procedure, cited in MIL-C-48497A, Coating, single or multilayer interference: Durability requirements for, any visor coating is visually examined by reflection, with the unaided eye, for evidence of flaking, peeling, cracking, or blistering. The inspection is performed using two 15-watt fluorescent light tubes as the light source. The viewing distance from the visor to the eye is less than 18 inches. The visors are viewed against a black matte background.

If MIL-V-43511C criteria are used, then each defect is classified as critical, major, or minor by the definitions in MIL-V-43511C, page 7, Table I. The number of critical, major, and sum of major and minor defects are compared to the criteria.

If the IHADSS criteria are used, the identified defects are classified as follows:

Gross flaw - Any pit, scratch, dig, bubble, inclusion, etc., which exceeds 0.034 inch in diameter or 0.100 inch long by 0.010 inch wide.

Blemish - Any pit, scratch, dig, bubble, inclusion, etc., which is equal to or less than 0.034 inches in diameter or 0.100 inches long by 0.010 inches wide and no less than 0.015 inches in diameter.

Cluster - Three or more blemishes within a 0.50 inch diameter zone.

Nuclear flashblindness protection

If HIDSS operation is expected in a tactical nuclear scenario, then any required nuclear flashblindness protective devices shall meet specific performance for luminous transmittance, distortion, prismatic deviation, refractive power, and optical density.

Luminous transmittance - The amount of visible light transmitted through the NFPD to the eye under photopic and scotopic conditions in the open state shall be determined. A minimum of 30 percent photopic luminous transmittance has been recommended for night use.

Distortion - The NFPD's lenses, when used to view the test line grating, shall not produce "objectionable" levels of distortion. Two optical areas are evaluated: (1) the central portion of each lens encompassing an area corresponding to 20 degrees about the optical center as subtended at the eye, and (2) the peripheral area beyond the 20 degrees. Testing is typically performed using an Ann Arbor optical tester (with a 50-line grating). The optical distortion is determined by inserting the device with its surface normal to the line-of-sight into the testing apparatus. Both the right and left optics of the NFPD shall be tested. A scale of 0-5 is applied, where 0 represents no distortion and 5 equates to a totally unacceptable level of distortion. Typically, distortion values of 3 or greater within the central optical area shall be reported as unacceptable. Values of 4 or greater in the peripheral area shall be reported as unacceptable.

Prismatic deviation - The algebraic difference between the vertical prismatic deviation of the center points (and other conjugate pairs) for the right and left eyes shall be no more than 0.18 diopter nor shall the vertical prism exceed 0.18 diopter at these points. The algebraic sum of the horizontal prismatic deviation of the center points (and other conjugate pairs) for the right and left eyes shall not exceed 0.50 diopter. The algebraic difference between the horizontal deviation at the center points shall not exceed 0.18 diopter.

Both vertical and horizontal prismatic power shall be measured at the left and right center points and at all other points of interest.

Base up prism shall be designated positive (+) and base down prism shall be designated negative (-). Base out prism (temporally deflected) shall be designated as positive (+) and base in prism (nasally deflected) shall be designated negative (-).

The vertical prismatic deviation values are determined by calculating the algebraic difference between the pairs of conjugate points. The horizontal prismatic deviation values are determined by calculating both algebraic sum and difference for the conjugate pairs.

Refractive power - The spherical refractive power of the NFPD device at the center points and other selected points shall not exceed ±0.125 diopter. The cylindrical refractive power shall not exceed ±0.0625 diopter.

Optical density - Optical density shall be measured for the closed state. A high luminance source (10,000 footlamberts or greater) shall be used as a reference source. Luminance measurements are taken at the center points of the right and left optics, as defined by the lines of sight in the "as worn" position. In devices using cross polarization, a luminance pattern (Maltese Cross) may be present in the closed state (McLean and Rash, 1985). In these devices luminous transmittance shall be measured at the most luminous section of the pattern.

MANPRINT issues

In addition to hazards resulting from performance degradation, other issues addressing safety and training need to be considered. These issues fall under the auspices of the U.S. Army's Manpower and Personnel Integration and Training program. In general, the HIDSS shall be required to incorporate design features which promote the health and safety of those personnel who will use and maintain the HIDSS. Hazards which may result in adverse explosive, fire, mechanical, or biological effects on personnel during HIDSS operation, test, training, and maintenance shall be eliminated or minimized to an acceptable level.

The design of the HIDSS, to include all cables and restraints, shall be compatible with the RAH-66's escape envelope and ingress/egress requirements and procedures. It is recommended that the HIDSS connection to the airframe be of a single point release design.

HMD systems such as the HIDSS are an integration of an optical display and a protective helmet. Such systems require special consideration for the process of fit. The basic fitting procedure can involve numerous steps. The goals of a satisfactory fit include obtaining a comfortable, stable fit, enabling the user to achieve and maintain the maximum FOV provided by the display system, and ensuring boresight capability, which permits accurate engagement of weapons systems during all flight maneuver envelopes.

As a result of experience with fitting the AH-64 IHADSS, Rash et al., reported in 1987 that a successful fitting program was essential to the acceptance and performance of integrated helmet and display systems. Recommendations for designing a successful fitting program included the designation of fitting responsibility (Army), a defined written fitting procedure, formal training for designated fitters, and availability of a stand alone fitting kit providing all necessary tools.

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